Inspection Policies for Hydraulic Steel Structures

Navigation Lock and Dam Inspection and Emergency Repairs Workshop

U.S. Army Engineer Research and Development Center

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Vicksburg, MS

Terminology

- FCM = Fracture Critical Member

  "members and their associated connections subjected to tensile stresses, whose failure would cause the structure to collapse"

- NDE = Non-destructive examination
  - *Or* NDT = Non-destructive testing
  - *Or* NDI = Non-destructive inspection

Topics

- Inspection Requirements
- What to look for
- How to look
- Acceptance Criteria
- Where to look

Inspection Requirements for HSS

- ER 1110-2-100: *Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures*
  provides general requirements

- ER 1110-2-8157: *Responsibility for Hydraulic Steel Structures*
  provides requirements for HSS inspection

- EM 1110-2-6054: *Inspection, Evaluation, and Repair of Hydraulic Steel Structures*
  provides guidance & recommendations (how to) for HSS inspection

ER 8157 Types of Inspection

- Periodic Inspection
- Initial FCM Inspection
- Damage Inspection
- Final Inspection of Completed Construction

ER 8157 - Periodic Inspection

- Regularly scheduled inspection required by ER 110-2-100
- Determination of physical & functional condition
- Identify changes from previously recorded condition, developing problems
- Verify satisfaction of service requirements
- Critical components of structures with life safety consequences should be subjected to a thorough visual examination

ER 8157 – Initial FCM Inspection

- Required for existing structures with FCMs where failure would result in probable loss of life
- Intended to ensure that FCM with life safety impacts have been adequately fabricated and are free from defects that could cause failure (NDT required)
- Required to be performed only once, requirement is waived if compliance is documented during original fabrication
- All butt joints, and groove welds in T- and corner joints subjected to tensile stress shall be ultrasonically tested
- Acceptance criteria are defined by AWS D 1.1 for statically loaded or cyclically loaded structures, as appropriate
- Welds not meeting AWS acceptance criteria can be assessed for “fitness for purpose” (EM 6054, BS 7910)
- Welds not meeting acceptance criteria or that cannot be shown to be fit for purpose must be repaired before placed in service

ER 8157 – Damage Inspection

- Special inspection for identifying extent and magnitude of damage from accidents, wear or other natural causes
- Scope and detail must be sufficient to permit a thorough assessment of the condition and operability of the structure

ER 8157 – Frequency of Inspections

- Periodic Inspections
  - Each HSS must be expected at least every 25 years
  - When several of the same type of HSS exist on a project, at least one of each type must be inspected at each periodic inspection
  - If an HSS cannot be dewatered for a periodic inspection, it should be inspected whenever it is dewatered prior to or subsequent to the scheduled inspection
- FCMs
  - Fracture critical members should be thoroughly visually inspected every five years

EM 6054 – Structural Deterioration

- Corrosion
- Fracture
- Fatigue (cyclic loading)
- Fabrication defects
- Operation and Maintenance
- Unforeseen loading (overloads)

Weld Discontinuities; *what to look for*

- Profile Defects
  - Undercut, Underfill, Overlap, Concavity, Convexity, Excess reinforcement
- Volumetric Defects
  - Porosity, Inclusions, Incomplete Fusion, Incomplete Penetration
- Planar Defects
  - Incomplete Fusion, Incomplete Penetration, Delamination, Cracks

Porosity

Figure 1—Scattered Porosity

Figure 2—Surface Appearance of Piping Porosity

Incomplete Joint Penetration and Incomplete Fusion

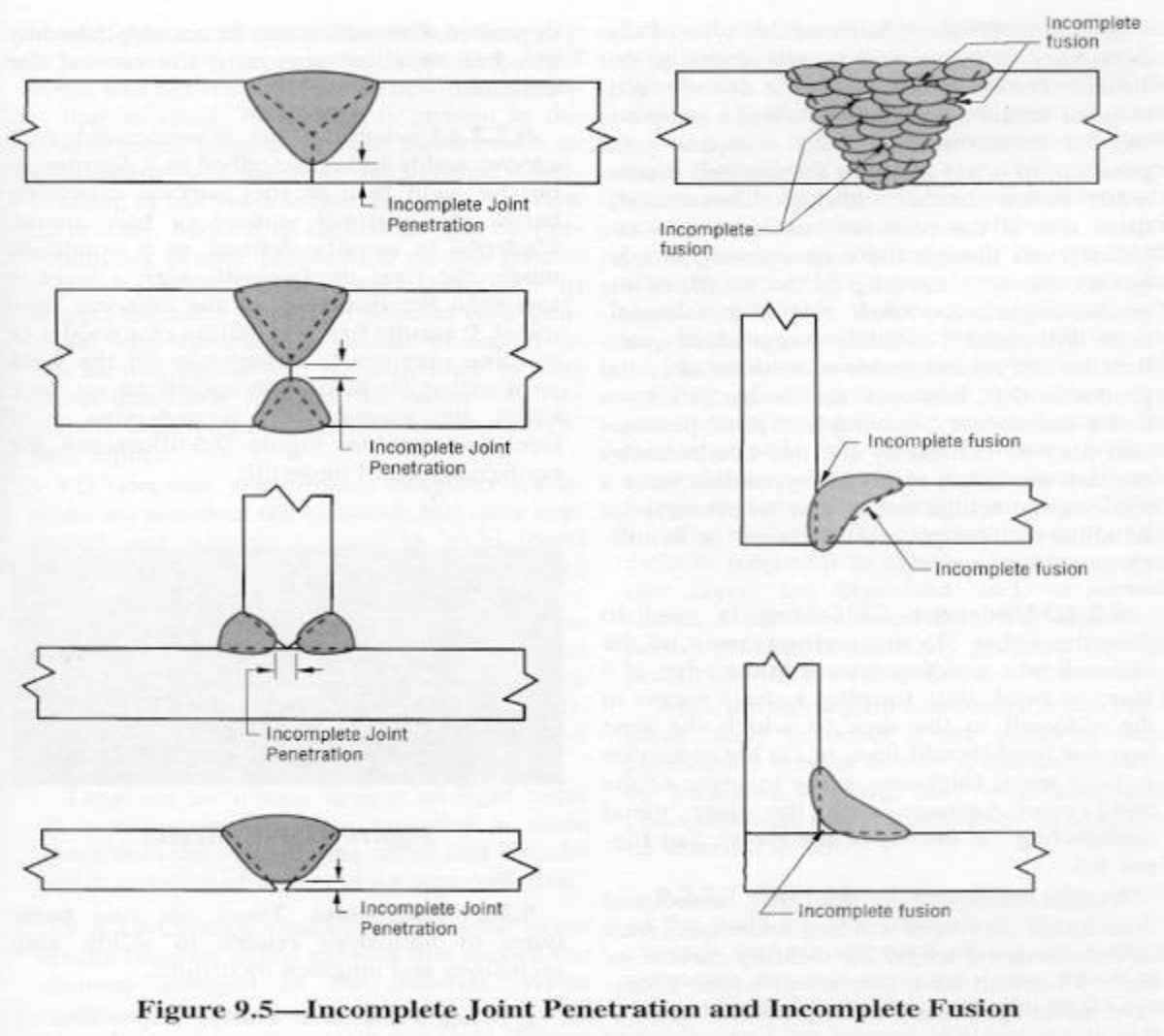


Figure 9.5—Incomplete Joint Penetration and Incomplete Fusion

Undercut and Overlap

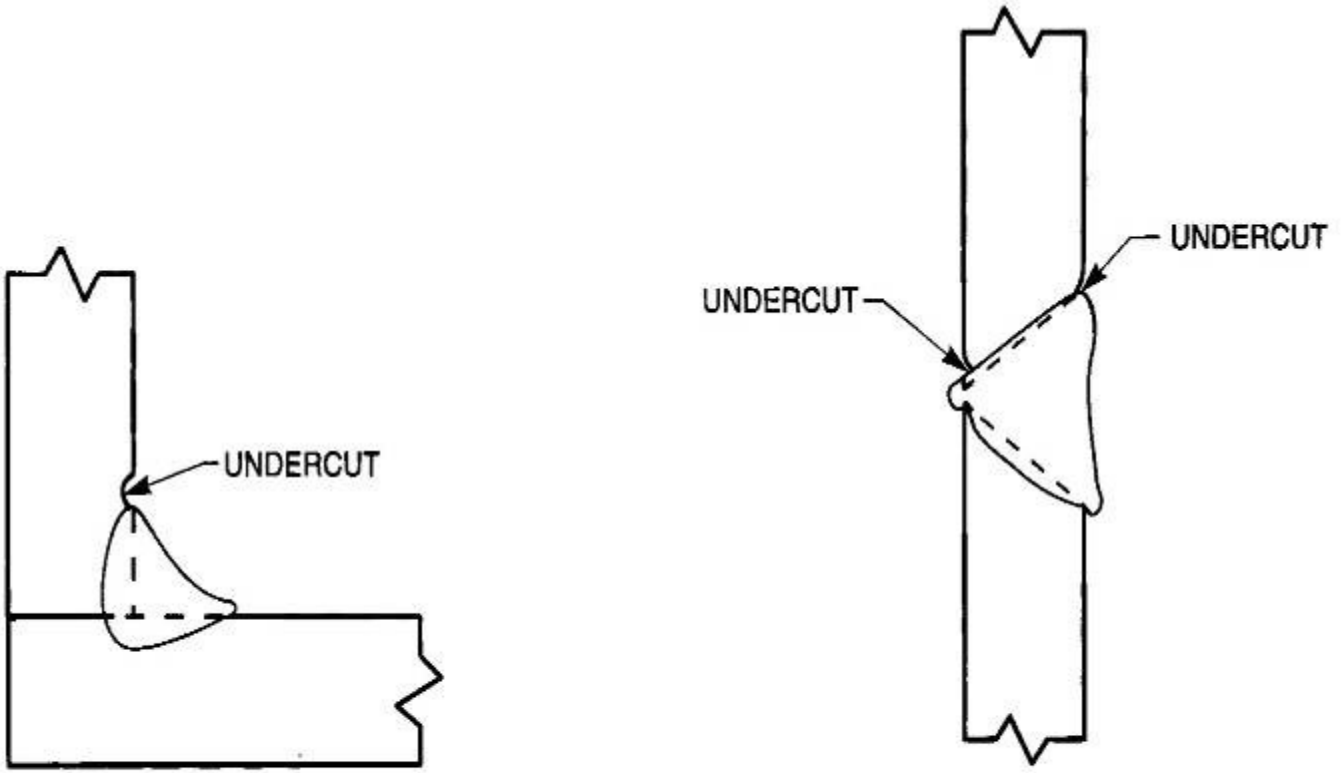


Figure 13—Examples of Undercut

Lamellar Tearing

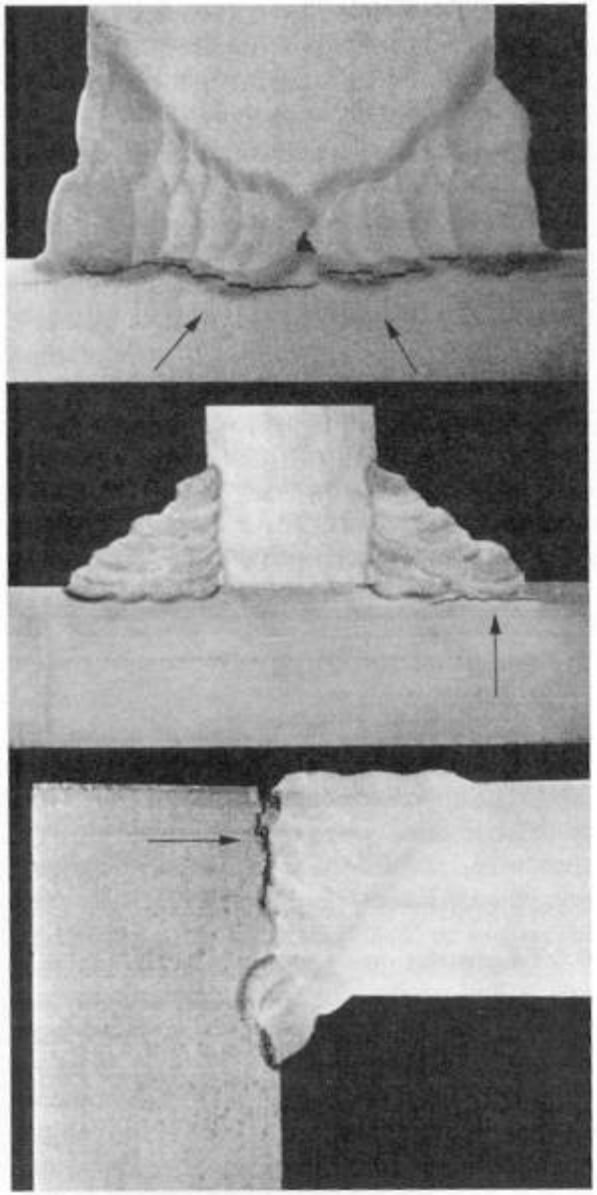


Figure 9.9—Lamellar Tearing

Cracks

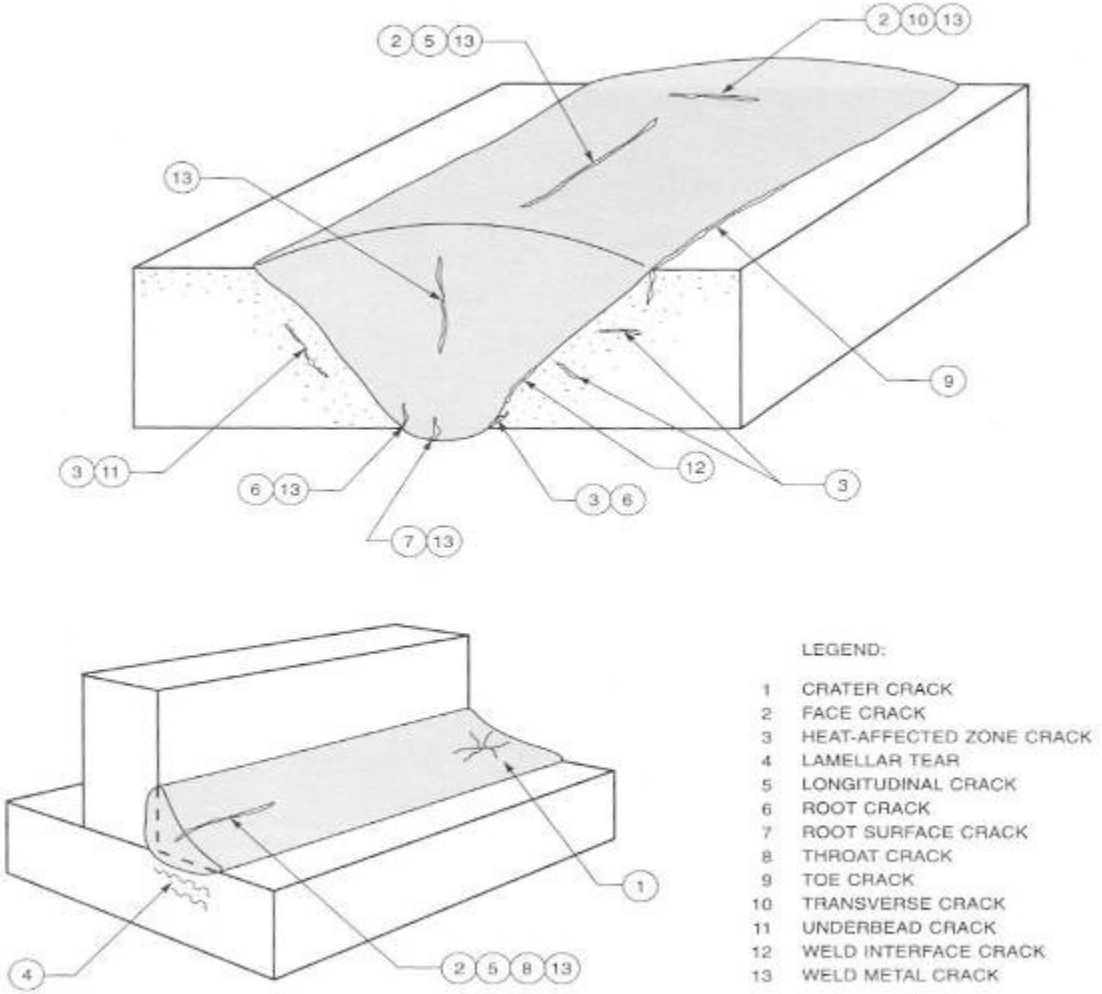
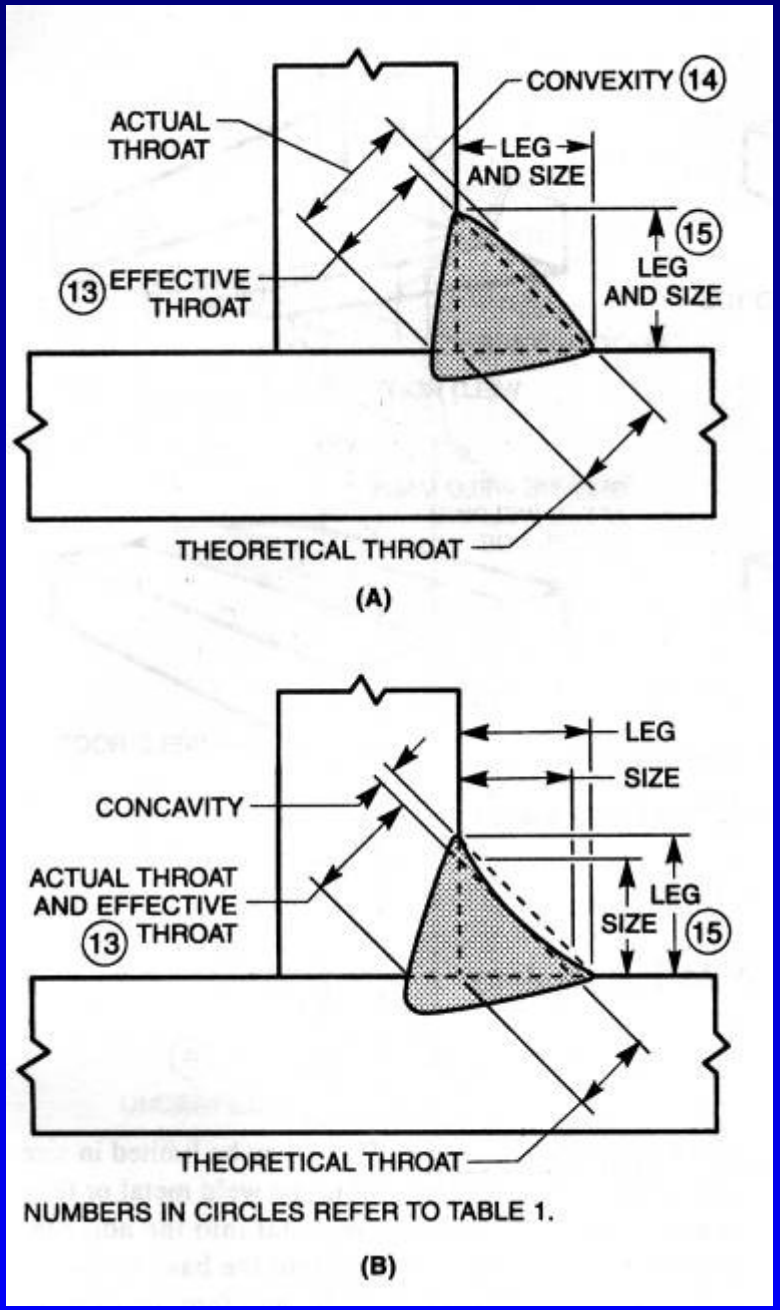


Figure 20—Types of Cracks

Convexity and Concavity



Review Discontinuities

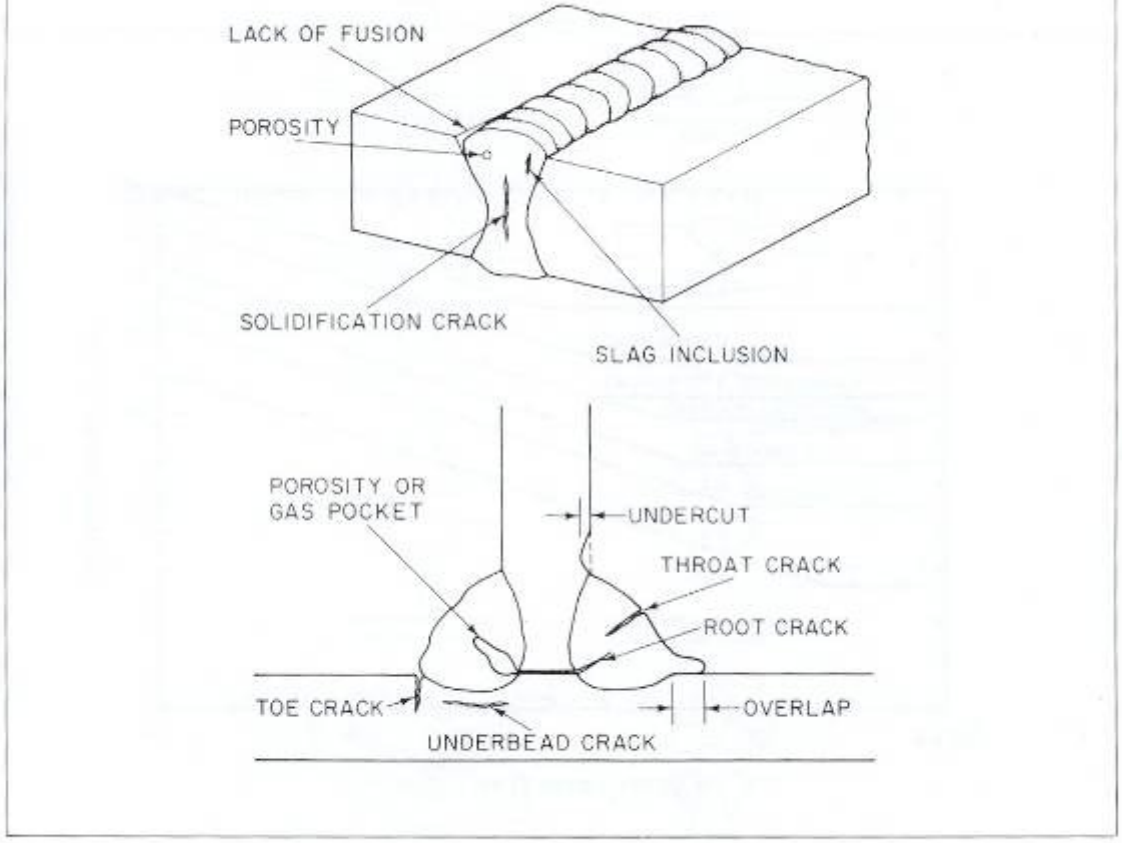
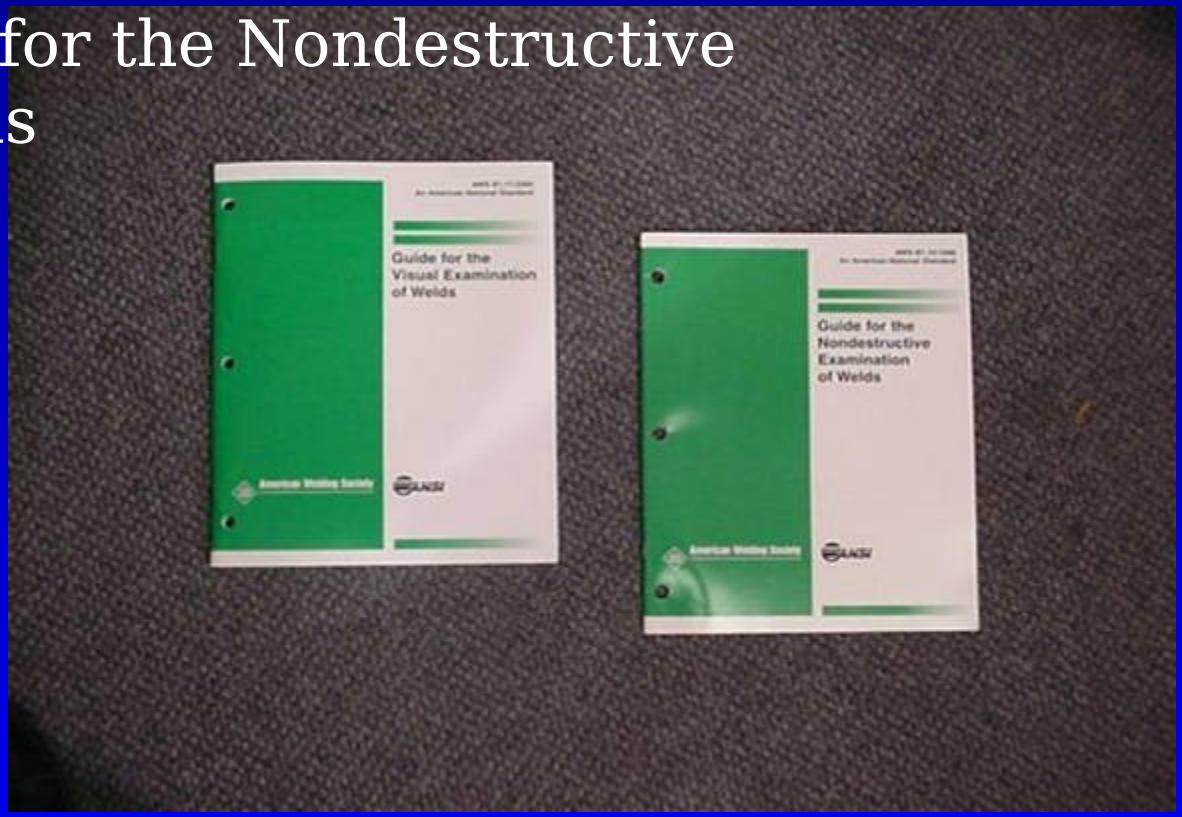


Figure 42.
Imperfections and cracks in welded joints.

Nondestructive Examination (how to look)

AWS B1.11 Guide for the Visual Inspection of Welds

AWS B1.10 Guide for the Nondestructive Inspection of Welds



ITL 97-1 Flaw Detection Practices for Steel Hydraulic Structures

Purpose of NDE

- Verify quality and integrity of welds and base metal without damage
- Data for assessment of a structure’s safety and function

The *Big Five* NDE Methods

- Visual Examination (VT)
- Penetrant Examination (PT)
- Magnetic Particle Examination (MT)
- Ultrasonic Examination (UT)
- Radiographic Examination (RT)

Visual Examination (VT)

- Often the primary and sometimes only inspection
- Effective form of quality assurance
- Most extensively used NDE method

Visual Examination
Advantages
Disadvantages

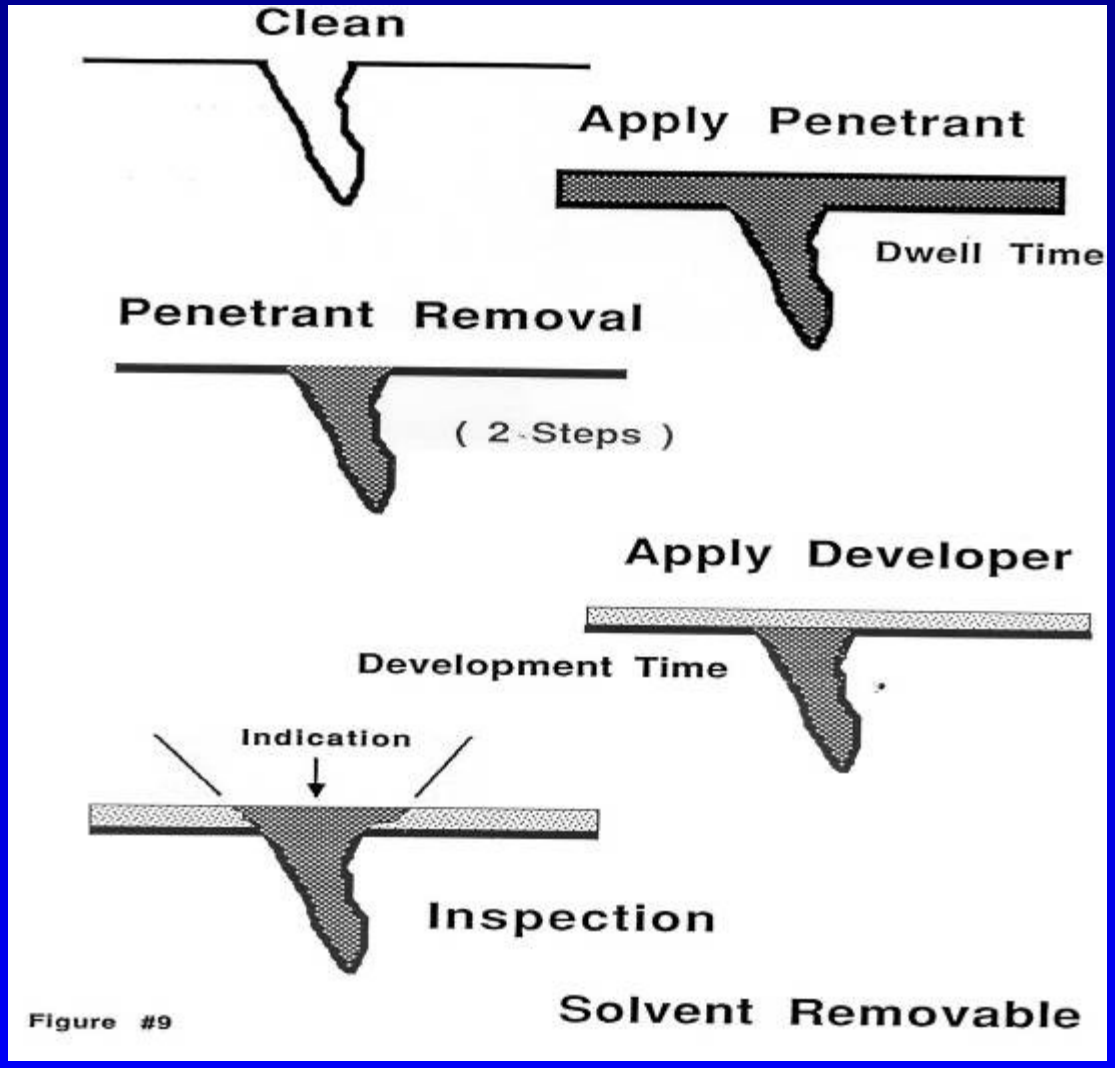
- Easy
- Quick
- Inexpensive
- Comprehensive
- Simple tools
  - Measuring tools
  - lighting
  - cleaning

- Requires experience
- Need clean, lighted area
- Surface only

Penetrant Examination

- A dye or fluorescent liquid *penetrant* seeps into cracks by capillary action
- Surface is cleaned, but penetrant is trapped in cracks
- cracks are revealed where the penetrant remains

PT Procedure



Penetrant Examination

Advantages

- Easy application
- quick
- Inexpensive
- Simple equipment
- Easy interpretation

Disadvantages

- Cleaning before and after
- Surface only
- Requires smooth surface

Magnetic Particle Examination (MT)

- Magnetic field is induced in tested component
  - electro-magnetization
  - Permanent magnets
- At cracks, magnetic field “leaks”
- Small magnetic particles (iron filings) placed on surface are attracted to “leaks” providing indication

MT Concept

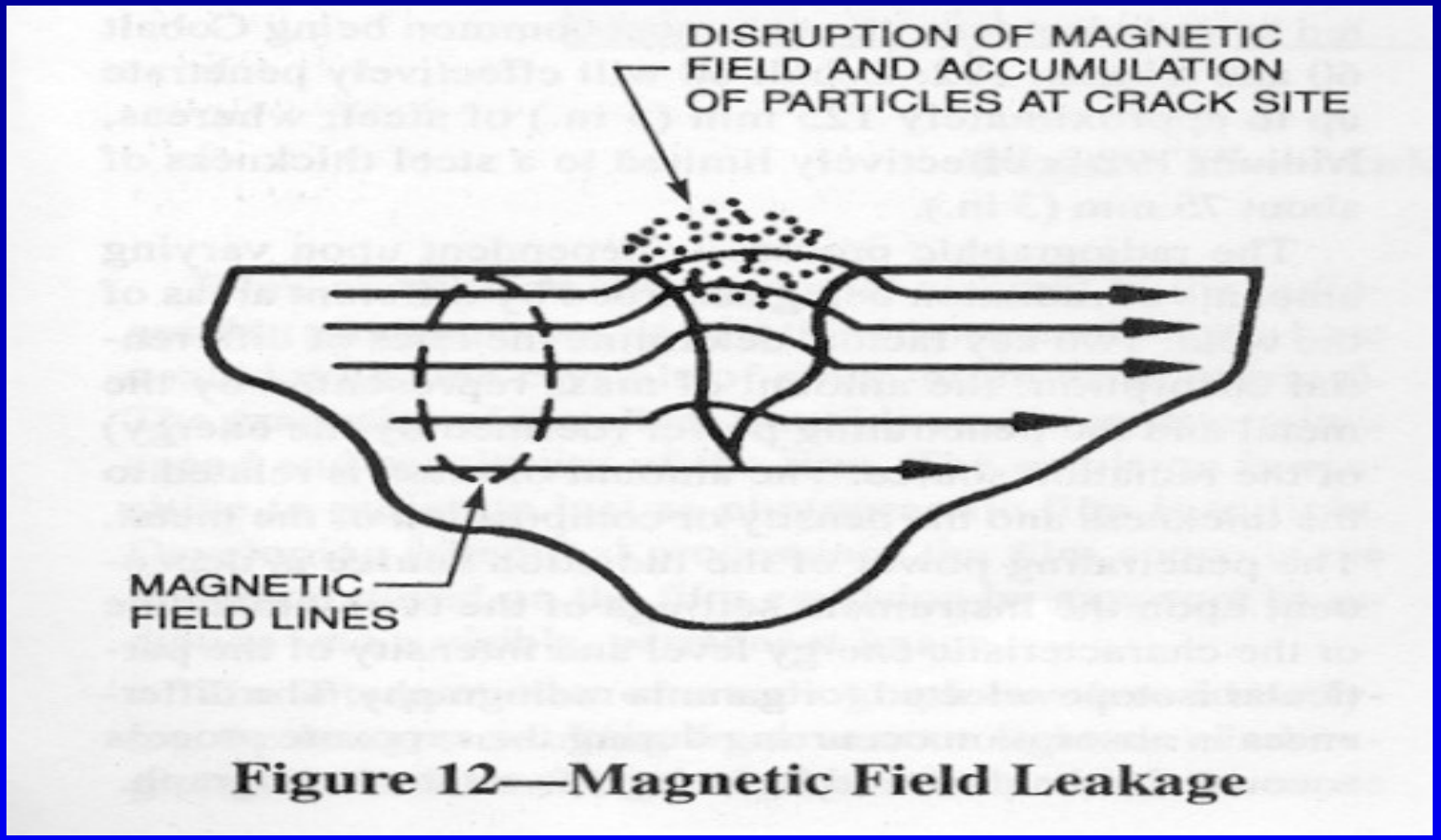


Figure 12—Magnetic Field Leakage

MT Concept

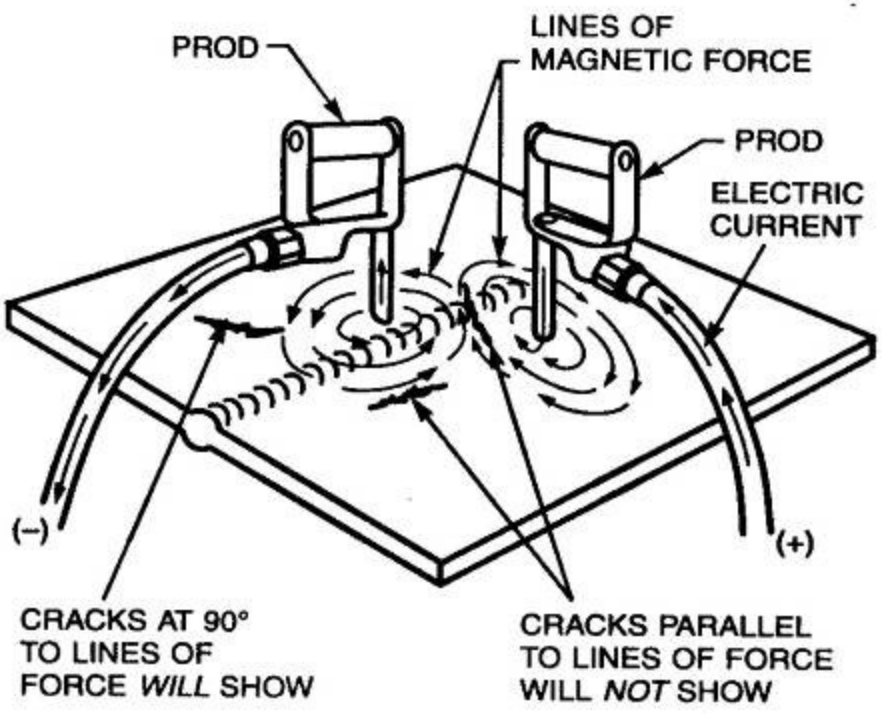


Figure 13—Direct Magnetization Using dc Prods

Magnetic Particle Examination

Advantages

- Easy
- Economical
- Quick
- Can go over thin coating
- Near surface flaws detectable

Disadvantages

- Ferromagnetic material only
- Electricity usually required
- Arc strikes
- No substantial sub-surface detection
- Detection can be difficult on rough surfaces

Ultrasonic Examination (UT)

- A sound wave is directed through tested material
- Sound waves reflect at interface of different medium
- Discontinuities are revealed by un-expected rebound sound waves

UT Concept

Distance = Velocity × Time

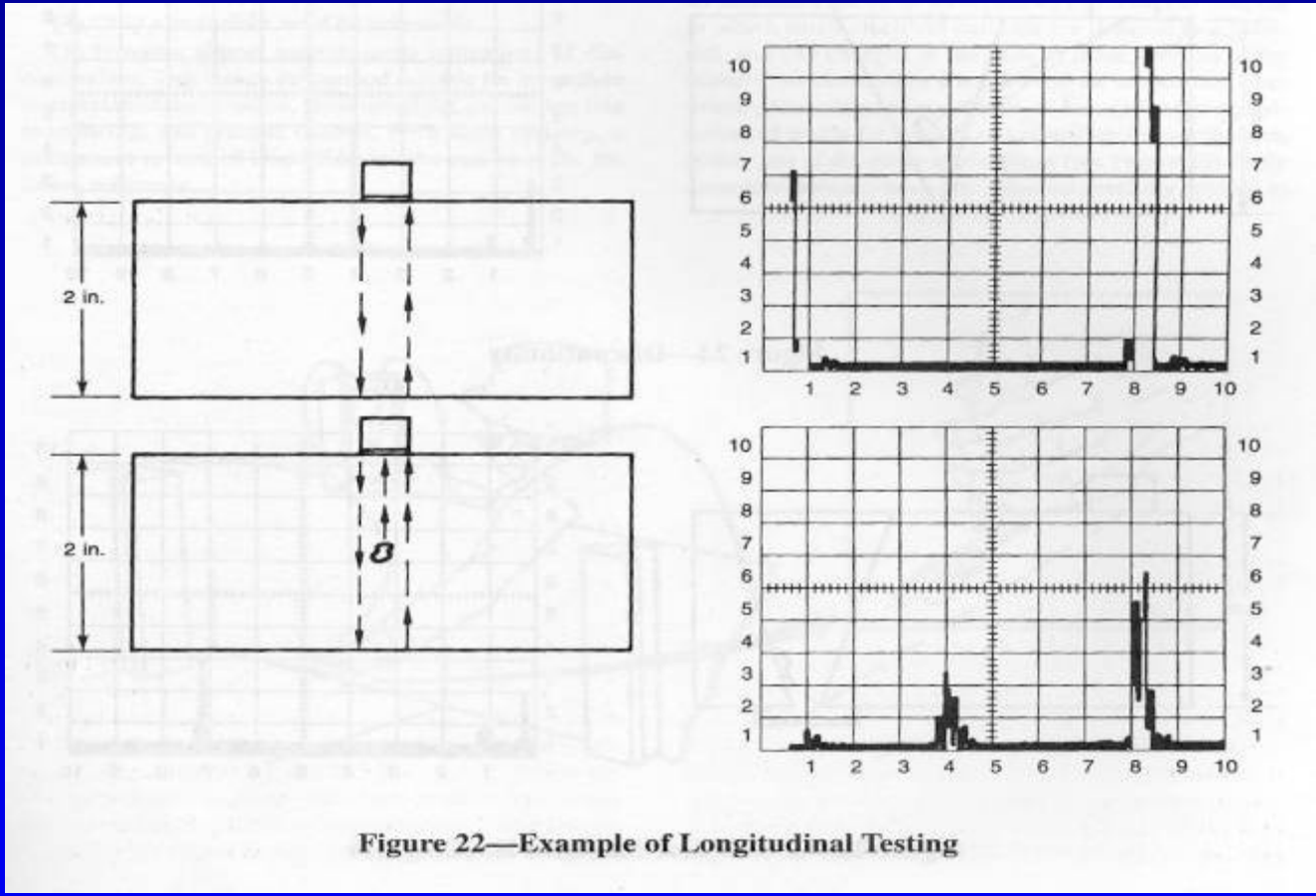


Figure 22—Example of Longitudinal Testing

UT Concept

- Signal path analogous to light reflection
  - Use shear waves
  - Vary transducer orientation

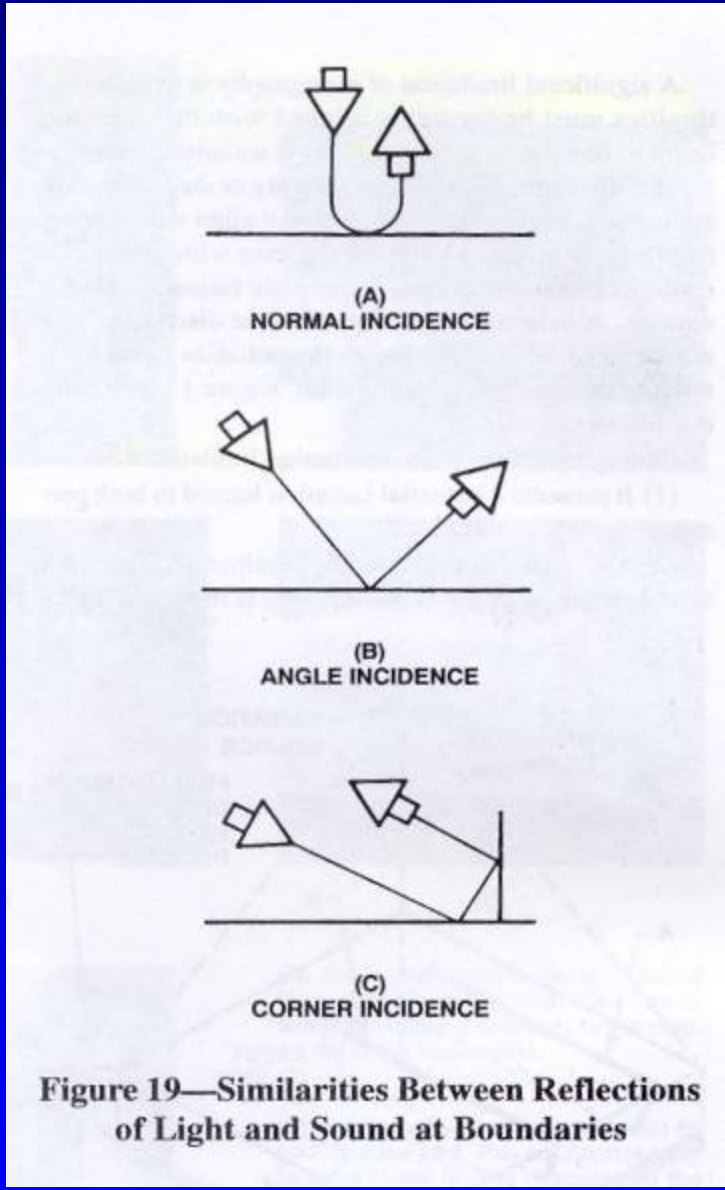


Figure 19—Similarities Between Reflections of Light and Sound at Boundaries

UT Field Inspection

UT Field Inspection

UT Field Inspection

Ultrasonic Examination

Advantages

- Deep penetration
- Immediate result
- Versatile
- Accurate
- Planar discontinuities

Disadvantages

- Smooth surface (prep)
- Skilled operator required
- Fillet welds

Radiographic Examination (RT)

- Radiation is passed through the test piece
- Radiation is absorbed by the test piece
  - Thick or dense areas absorb more
  - Thin or open areas absorb less
- Film measures passed radiation providing indication
  - Light areas represent areas hard to penetrate
  - Dark areas represent areas easy to penetrate (discontinuity)

RT Concept

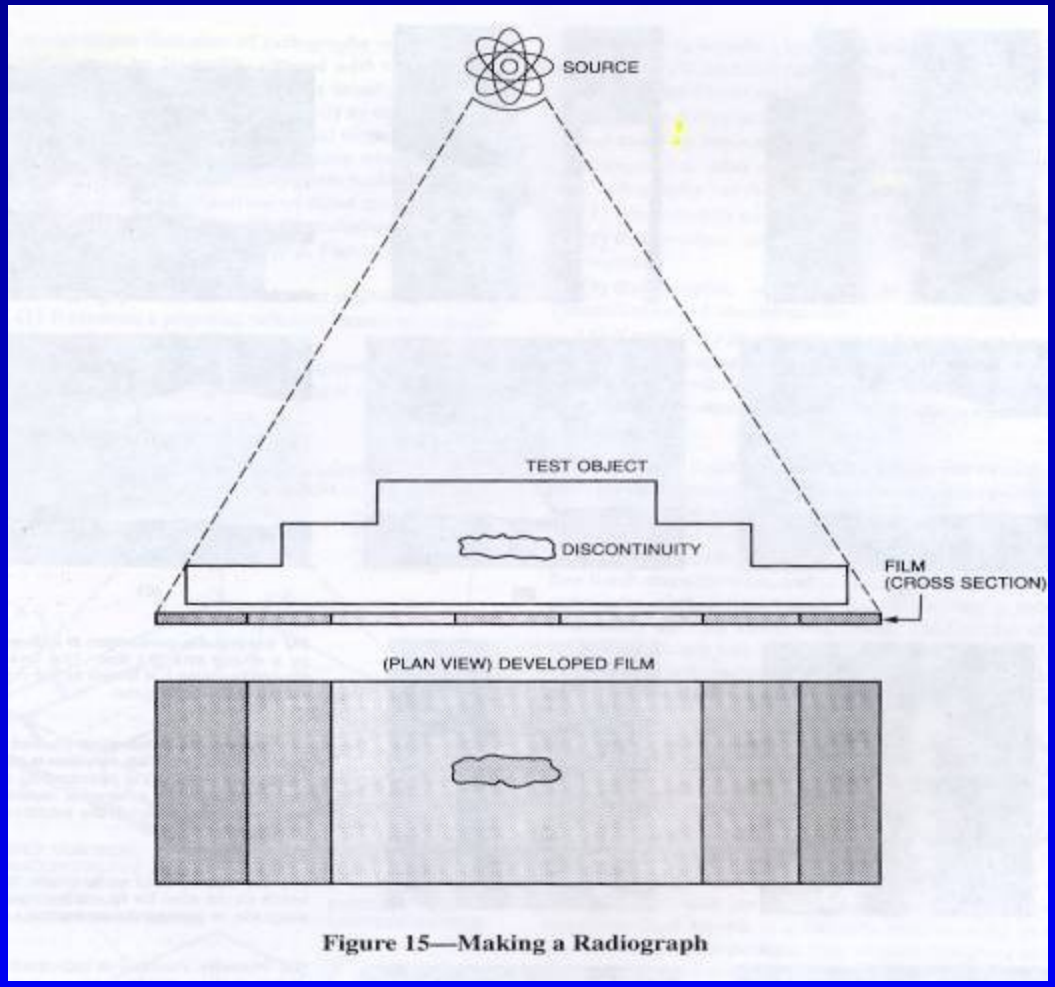


Figure 15—Making a Radiograph

RT Concept: Detection

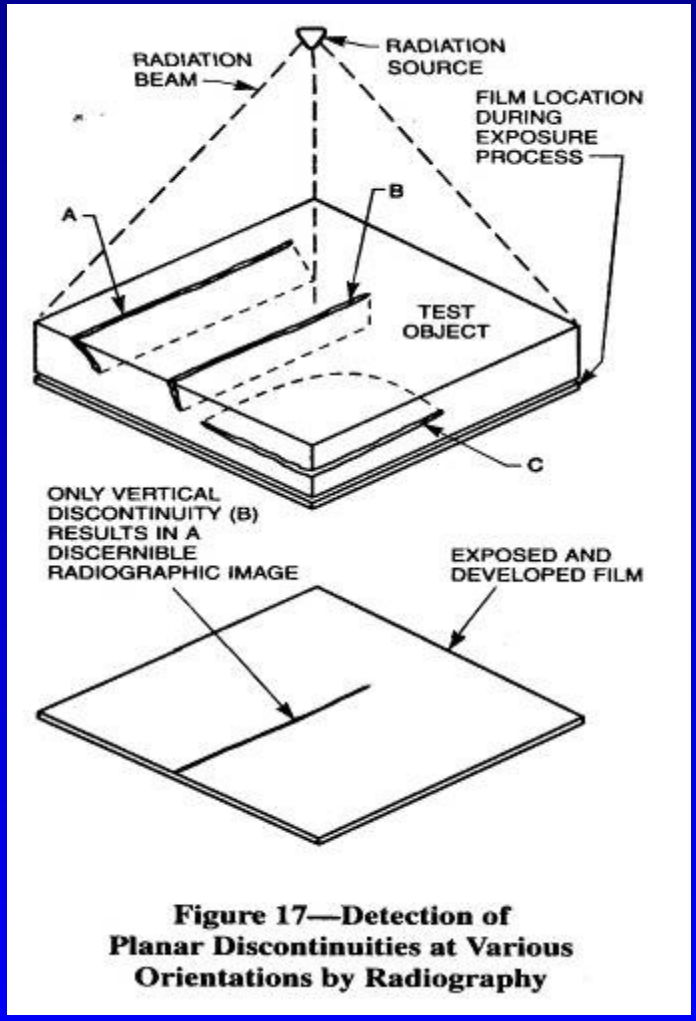


Figure 17—Detection of Planar Discontinuities at Various Orientations by Radiography

Radiographic Examination

Advantages

- Detects surface and internal
- Provides permanent record (to scale!)
- accurate

Disadvantages

- Planar discontinuity orientation
- Radiation hazard
- Initial cost
- Requires skilled operators/ interpreters
- Must access both sides

Examination vs. Discontinuity

	VT	PT	MT	UT	RT
Porosity / Slag Incl	G	G	P	P	G
overlap	G	G	G	F	P
Incomplete fusion	P	P	F	G	F
Incomplete jt penetration	P	P	F	G	G
Undercut	G	G	F	F	G
Cracks	G	G	G	G	F

Acceptance Criteria

- EM 1110-2-6054, ER 1110-2-8157:
  AWS D1.1
  - Weld profile requirements
  - Planar type discontinuities not accepted
    (cracks)
  - Non-planar discontinuities have specified limits
    (porosity, slag inclusion)
- EM 1110-2-6054
  - Assessment procedures

Acceptance Criteria

- Acceptable flaw sizes

  Must distinguish between acceptance levels based on

  – Welding quality control

  – Fitness for purpose

Acceptance Criteria

- AWS acceptable flaw sizes are based on a quality of workmanship criteria
  - Achievable by a competent qualified welder using proper procedures and welding parameters
  - Somewhat arbitrary, but useful for identifying quality control or workmanship problems
  - Conservative from a fitness for purpose perspective

"The criteria … should not be considered as a boundary of suitability for service. Suitability for service analysis would lead to widely varying workmanship criteria unsuitable for a standard code" - AWS D1.1 Commentary

Acceptance Criteria

- Fitness for purpose acceptable flaw sizes are based on a fracture mechanics analysis
  - Service loads + Secondary (residual) stresses + Peak stresses (stress concentration)
  - Material Properties
  - Environment
  - Consequences of failure

Fitness for Purpose

- Benefits of fitness for purpose evaluation
  - Based on an engineering assessment
  - Avoid unnecessary repairs (time and money)
  - Avoid introduction of unintended flaws as a result of unnecessary repairs
  - Identifies limiting conditions for failure
  - Usually only necessary when applicable quality control standards are not met

Critical Areas – Where to look

ER 8157

Prioritize Members

1. FCMs with life safety impacts
2. Other FCMs
3. Primary tension members or tension elements
4. Primary compression members or compression elements
5. Secondary structural members
6. Non-structural items

Critical Areas – Where to look

EM 1110-2-6054

"Periodic inspection should be a systematic and complete examination of the entire structure with particular attention given to the critical locations."

Preparation – *it pays*

- Review project drawings
  - Geometry
  - Material
  - Access
- Review prior inspection reports
  - Identify baseline
  - Identify prior problems
- Review recent maintenance records

Preparation *continued*

- Develop an inspection plan
  - Identify critical locations
  - Identify methods and procedures
  - Plan access to structural elements
- Prepare an inspection notebook
  - Identify critical areas
  - Drawings for inspection notes
  - Blank Photo log sheets

Critical Areas for Fatigue & Fracture

- Fatigue life is a function of
  - Stress Range
  - Geometry
- Fracture Stress Intensity $K_I = C \sqrt{a}$
  - Stress
  - Geometry

Identify Critical Areas for Fracture

- *Stress*: Locate high tensile stress (Simple 2-D analysis)
- *Geometry*: Identify details with high stress concentration (Fatigue category)
- Displacement induced stress location
- Thick plate welds
  - Residual stress
  - Low toughness

Typical Critical Areas

- FCM
- High tensile stress / low fatigue strength category
- Lifting connections
- Support locations

Typical Critical Areas

Examples for common gate types from

EM 1110-2-6054

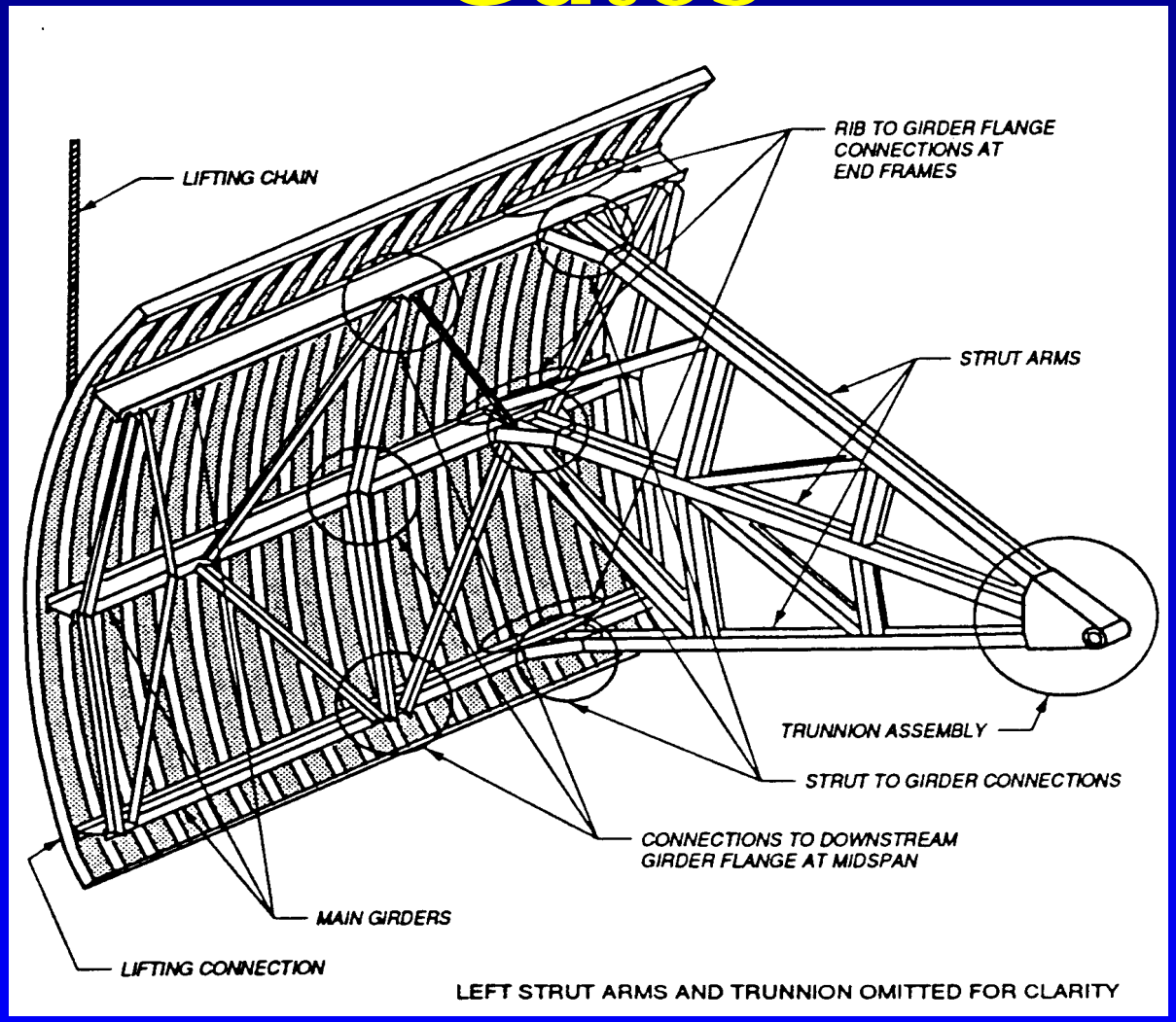
Critical Areas: Tainter Gates

- Trunnion weldments
- Steel trunnion girders
- Lifting bracket
- Upstream girder flange near end frame
- Downstream girder flange/brace connection near midspan
- Girder-to-strut connection

Trunnion Assembly
Thick Plate Weldments

End Frame/Trunnion Connection Thick Plates / High Tension

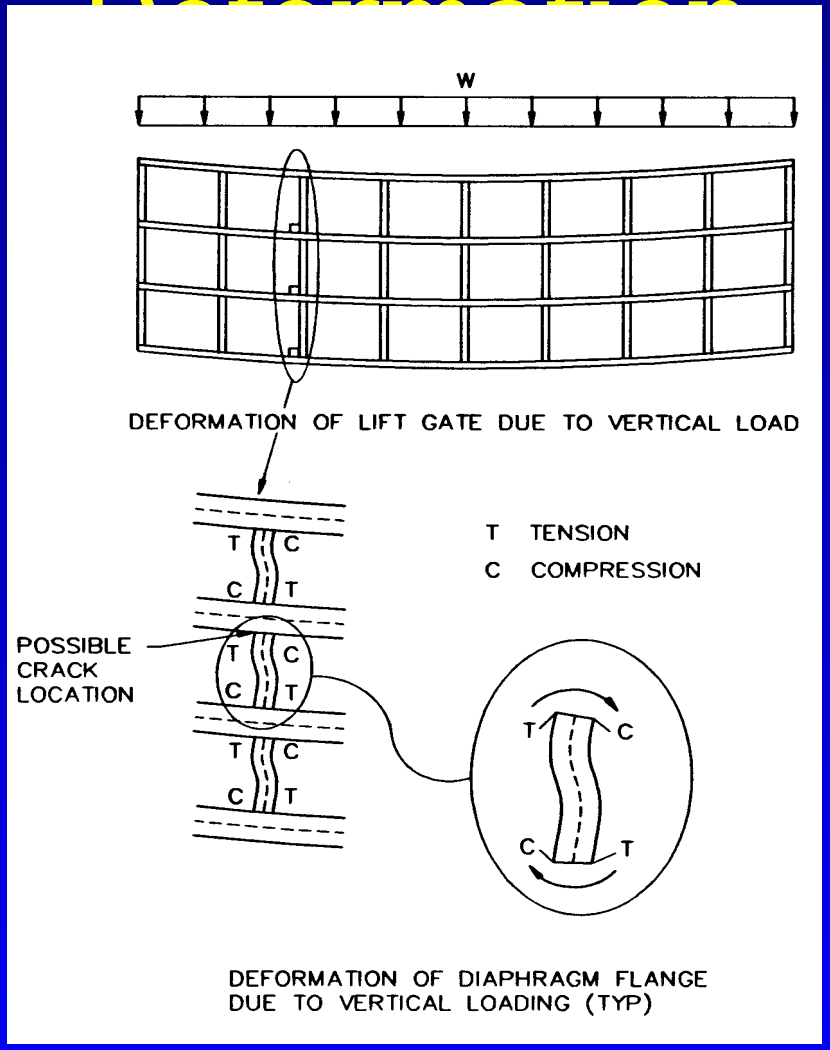
Critical Areas for Tainter Gates


LIFTING CHAIN
RIB TO GIRDER FLANGE CONNECTIONS AT END FRAMES
STRUT ARMS
TRUNNION ASSEMBLY
STRUT TO GIRDER CONNECTIONS
CONNECTIONS TO DOWNSTREAM GIRDER FLANGE AT MIDSPAN
MAIN GIRDERS
LIFTING CONNECTION
LEFT STRUT ARMS AND TRUNNION OMITTED FOR CLARITY

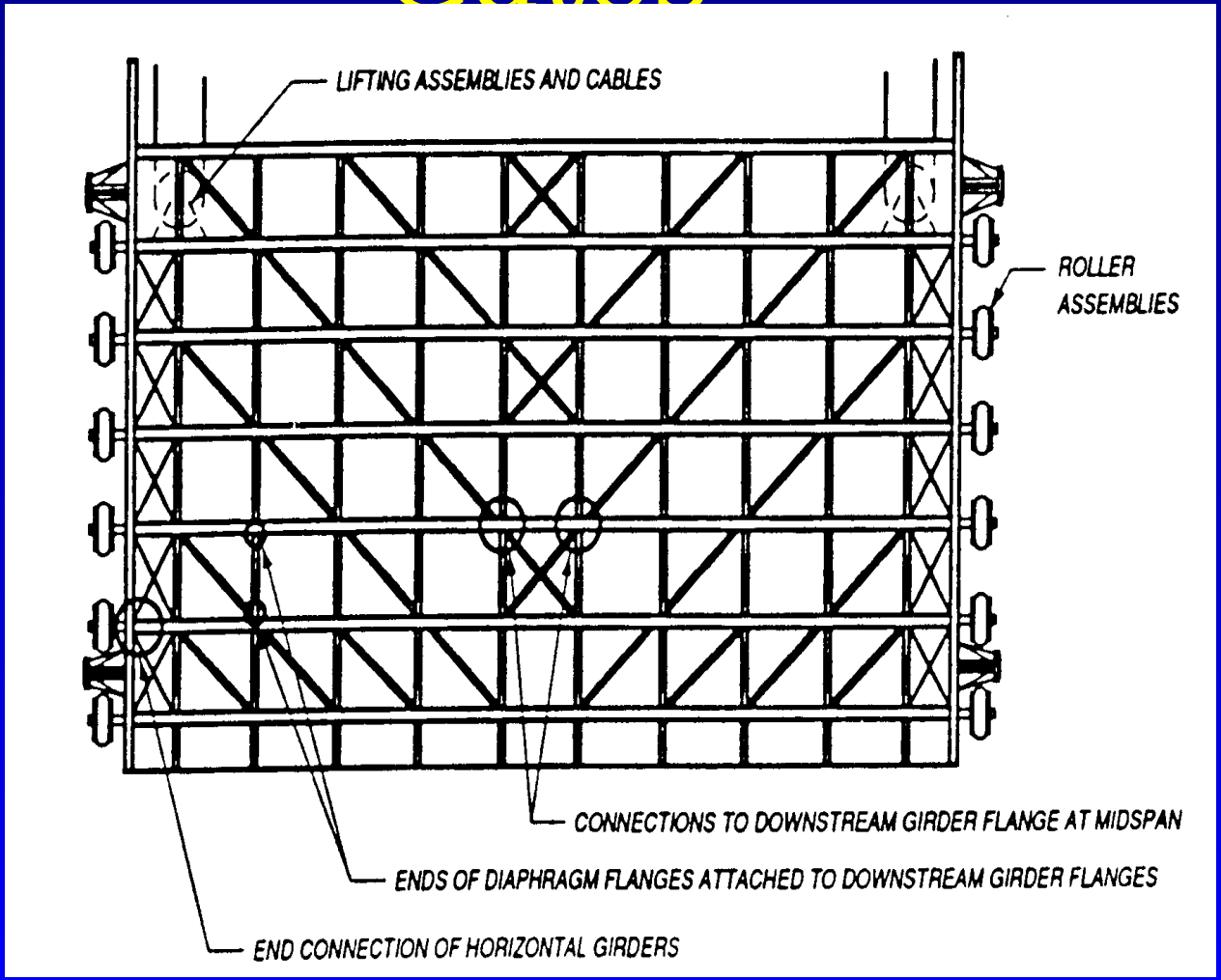
Critical Areas for Lift Gates

- Downstream girder flange (horizontal load)
- Lower leg of DS girder flange (vert. load)
- Distortion induced stress at diaphragm-to- girder connection
- Lift connections
- Girder ends

Lift Gate Leaf Vertical Deformation



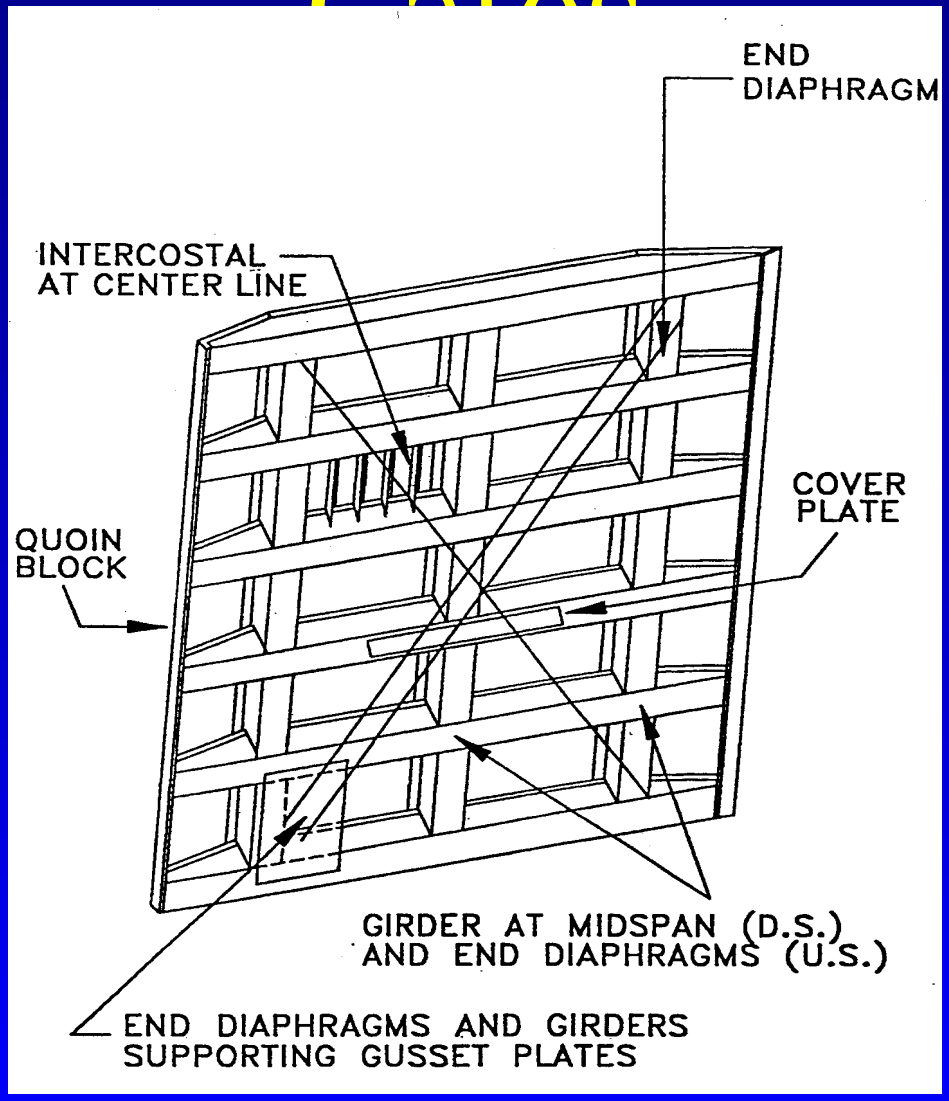
Critical Areas for Lift Gates


LIFTING ASSEMBLIES AND CABLES
ROLLER ASSEMBLIES
CONNECTIONS TO DOWNSTREAM GIRDER FLANGE AT MIDSPAN
ENDS OF DIAPHRAGM FLANGES ATTACHED TO DOWNSTREAM GIRDER FLANGES
END CONNECTION OF HORIZONTAL GIRDERS

Critical Areas for Miter Gates

- Downstream girder flange connections near midspan
- Diaphragm – girder interface near miter and quoin (thick plates / residual stress)
- Diagonal connections
- Anchorage
- Pintle area

Critical Areas for Miter Gates



Field Inspection Comments

- Follow your plan
- Equipment
- Cleaning: must be able to see
- Access Considerations
  - Climbing
  - Scaffold (rigging)
  - Inspection access vehicle (snooper/manlift)
- Recording
  - Notes
  - Photographs

Structural Instrumentation

- Supplement inspection
- Use it! It can often be quick and inexpensive

Questions?